

are at least as accurate as those of Ludwig's method, while it is far easier to carry out, and occupies much less time.

- VI. "On the Potential Difference required to produce a Spark between two Parallel Plates in Air at Different Pressures."
By J. B. PEACE, M.A., Fellow of Emmanuel College, Cambridge. Communicated by Professor J. J. THOMSON, F.R.S.
Received May 24, 1892.

Introductory.

The following is an account of an investigation into the relations between potential difference, spark-length, and pressure when discharge takes place between two parallel plates in air. The investigation was undertaken at the suggestion of Professor J. J. Thomson, and has been carried out in the Cavendish Laboratory in Cambridge.

Preliminary experiments were made in July and August, 1890, in which a small Wimshurst machine was used, and the potential difference was measured by one of Lord Kelvin's vertical electrostatic voltmeters. For sparks of some length fairly consistent results were obtained, but in the case of short sparks accurate measurement of the potential difference was difficult. Use was then made of a large number of small secondary cells, and, at the same time, more accurate measurements of the spark-length were made. At first about 500 cells were used, so that steady potential differences, ranging up to about 1,000 volts, could be maintained, and sparking differences up to about 0.1 mm. were examined. The results of these experiments showed very fair agreement with those of other observers; they were sufficiently consistent among themselves to show that the cells could be relied on. More cells were therefore set up, and all were carefully tested as to equality, rate of fall of charge, &c.

Apparatus was then constructed by which discharge at different pressures could be examined. Description of this apparatus, which is sketched in fig. 1, and an account of the method and results of observations made with it in July and August, 1891, are given in Part I below. At first some difficulty was found in making the bell-jar and its connexions sufficiently air-tight, but when this was overcome an effect similar to that observed by De la Rue and Müller in discharge in exhausted tubes became apparent; that is, it was found that, as the pressure diminished, the potential difference required to produce a spark across a given distance fell to a minimum value, and then began to increase rapidly. To examine this effect more fully, the observations were confined to pressures ranging from 20 to

II 2

300 mm. of mercury, the water-pump which was used, and the stuffing-box through which the sparking distance was adjusted, not admitting of observations at lower pressures. The results of these observations are tabulated below, and appear in the curves in figs. 2, 3, and 4.

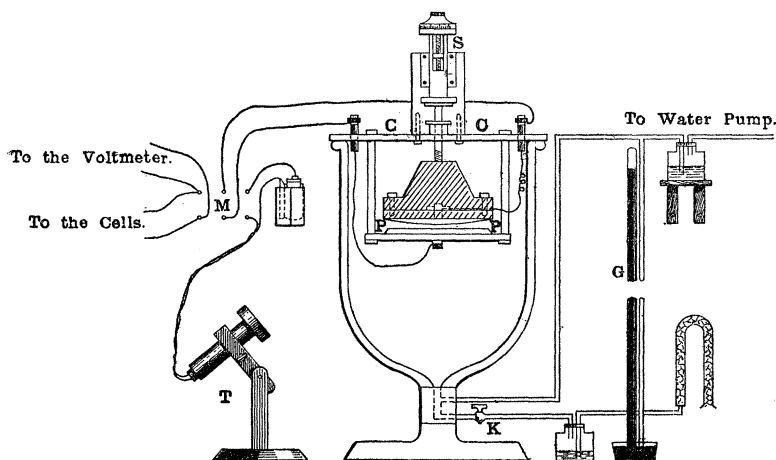
When these results were examined and compared, it was found that the curves connecting potential difference and pressure not only exhibited the minima above mentioned, but also crossed each other, showing that at low pressures the shorter spark required the greater potential difference. As this seemed a point of some importance, it was decided to make a more direct investigation, and with this view apparatus was constructed and observations made in April, 1892. This apparatus is described, and the results obtained are recorded in Part II below. The observations were confined to pressures ranging from 2 or 3 up to 50 mm. of mercury, and the results confirmed and extended those formerly obtained.

PART I.

A sketch of the apparatus used is given in fig. 1. An inverted bell-jar, communicating with a water-pump, had its mouth ground and fitted with a brass cover, C. This cover carried the attachments of the discharge plates P, P, and the micrometer screw S. The screw had a pitch of $\frac{1}{50}$ inch, and its head was graduated in hundredths of a revolution. A short steel rod, fixed to the sliding frame of the screw and working through a stuffing-box in the centre of the cover C, carried an insulating block, to which the upper discharge plate could be readily attached. The lower plate was fixed to an ebonite disc which was rigidly suspended from the cover C. The plates were of brass, highly polished, and were about $2\frac{5}{8}$ inches in diameter. The lower plate was plane, the upper was slightly convex, having a radius of curvature of about 9 inches. Short flexible wires passed from the plates to insulated terminals passing through the cover. From these terminals leads passed to mercury cups, M, by which connexion could be made, on the one hand with the leads of the telephone T, and, on the other hand, with leads passing to the secondary cells and to the voltmeter.

The cells were arranged in groups of eighteen in series; for charging, the groups were arranged in parallel; for spark discharge they were arranged in series, while the leads passing to M could be connected to the terminals of any required number of cells. In the discharge circuit there were also a simple make-and-break key and a very high resistance, the latter to prevent the setting up of an arc discharge between the plates. This resistance was usually a black-lead line on a strip of ebonite.

FIG. 1.



The path from the bell-jar to the pump passed through sulphuric acid, and was also connected to a mercury gauge, G. Air could be admitted to the jar through the stop-cock K, after passing through cotton wool and sulphuric acid.

The following was the usual course of a series of observations:— While the cells were charging, which generally occupied about one half hour, the plates were polished and fixed in position, the cover fitted to the mouth of the bell-jar, and the pump put in action. The screw reading for contact of the plates was taken, the upper plate being moved downwards till contact took place and completed the telephone circuit. The plates were set at any required distance apart, the upper plate being, in all cases, moved downwards to its final position.

When the cells were charged they were allowed a few minutes to reach a steady state and were then joined up in series, and various groups of 500 tested by the electrostatic voltmeter; in this, the smallest weight being used, one scale division read 50 volts, so that direct reading gave ten times the voltage of a single cell. This measurement was repeated at intervals during each experiment, and only those observations were preserved in which the cells either remained practically constant, or fell in potential difference so slowly and uniformly that accurate allowance could be made.

The plates being now at a known distance and the air at a known pressure, regulated by the pump on the one hand and the stop-cock K on the other, the number of cells connected to the plates, always at first well under what was required to produce discharge, was gradually increased until the spark passed, and the potential difference

was taken as being proportional to the number of cells. The observations were made for a series of pressures ranging from 20 to 300 mm. of mercury.

When the apparatus was first used, a fixed potential difference was given to the plates, and the pressure gradually lowered until a spark passed. When, however, it was found that, in certain circumstances, a diminution of pressure required an increase of potential difference, this method was abandoned, and that described above was adopted.

Within the specified range of pressure a considerable number of observations were made in July and August, 1891, for spark-lengths corresponding to 2, 5, 10, 20, 40, 100, 200, and 400 divisions of the screw head. The mean results of these observations are given in the following tables. Each table represents the mean of at least three series of observations, taken at considerable intervals of time, and generally showing very close agreement with each other.

From the observed potential difference the electrostatic force has been deduced, that is, the potential difference (in electrostatic units) per centimetre of spark-length. The electrostatic force is given in the third column of the following tables, the first column containing the air pressure in millimetres of mercury, and the second the potential difference in volts, while d is the spark-length, as measured above.

The tables are represented by the curves of figs. 2 and 3, fig. 2 showing the connexion between potential difference and pressure for various constant spark-lengths, and fig. 3 showing the connexion between electrostatic force and pressure for the same spark-lengths. From these are deduced the curves in fig. 4, showing the relation between potential difference and spark-length for various constant pressures.

Curves A, fig. 2, and A, fig. 3. $d = 0.0004$ in.			Curves B, fig. 2, and B, fig. 3. $d = 0.001$ in.		
Pressure, mm. of mercury.	Potential difference, volts.	Electrostatic force, C.G.S. units.	Pressure, mm. of mercury.	Potential difference, volts.	Electrostatic force, C.G.S. units.
20	433	1420	20	430	564
30	398	1310	30	396	528
40	380	1245	40	377	495
50	370	1215	50	361	474
60	357	1170	60	354	465
70	353	1160	70	347	456
80	349	1145	80	343	450
90	346	1135	90	339	445
100	343	1125	100	336	440
120	337	1105	120	334	438
140	332	1090	140	331	434
160	330	1085	160	332	435
180	329	1080	180	334	438
200	328	1075	200	338	444
240	326	1070	250	352	463
280	327	1072	300	376	495
300	328	1075			

Curves C, fig. 2, and C, fig. 3. $d = 0.002$ in.			Curves D, fig. 2, and D, fig. 3. $d = 0.004$ in.		
Pressure, mm. of mercury.	Potential difference, volts.	Electrostatic force, C.G.S. units.	Pressure, mm. of mercury.	Potential difference, volts.	Electrostatic force, C.G.S. units.
20	426	278	20	421	138
30	393	265	30	383	126
40	373	244	40	365	120
50	360	236	50	355	116
60	352	231	60	355	116
70	344	225	70	360	118
80	340	223	80	369	121
90	336	220	90	380	125
100	334	218	100	390	128
120	334	218	120	416	136
140	340	223	140	442	145
160	348	228	160	470	154
180	358	235	180	491	161
200	374	245	200	515	169
250	414	271	250	573	192
300	456	300	300	626	205

Curves E, fig. 2, and E, fig. 3. $d = 0.008$ in.			Curves F, fig. 2, and F, fig. 3. $d = 0.02$ in.		
Pressure, mm. of mercury.	Potential difference, volts.	Electrostatic force, C.G.S. units.	Pressure, mm. of mercury.	Potential difference, volts.	Electrostatic force, C.G.S. units.
20	410	67	20	484	31.5
30	373	61	30	510	33.5
40	375	61	40	550	36.0
50	385	63	50	580	38.0
60	402	66	60	617	40.5
70	420	69	70	660	43.0
80	435	71	80	699	46.0
90	451	74	100	778	51.0
100	468	77	120	852	56.0
120	507	83	140	933	61.0
140	541	89	160	1000	65.5
160	575	94	200	1138	74.0
180	607	99	220	1208	79.5
200	645	103	240	1272	83.5
250	729	119	260	1340	88.0
300	802	132	280	1416	92.5
			300	1490	97.5

Curve G, fig. 2. $d = 0.04$ in.			Curve H, fig. 2. $d = 0.08$ in.		
Pressure, mm. of mercury.	Potential difference, volts.	Electrostatic force, C.G.S. units.	Pressure, mm. of mercury.	Potential difference, volts.	Electrostatic force, C.G.S. units.
20	528	17.3	16	550	9.0
30	589	19.3	20	635	10.4
40	662	21.8	30	800	13.1
50	731	24.0	40	950	15.6
60	824	27.0	50	1100	18.1
70	906	29.5	60	1255	20.5
80	970	31.8	65	1326	21.7
90	1046	34.2	75	1464	24.0
100	1116	37.2			
120	1260	41.4			
130	1326	43.5			

FIG. 2.

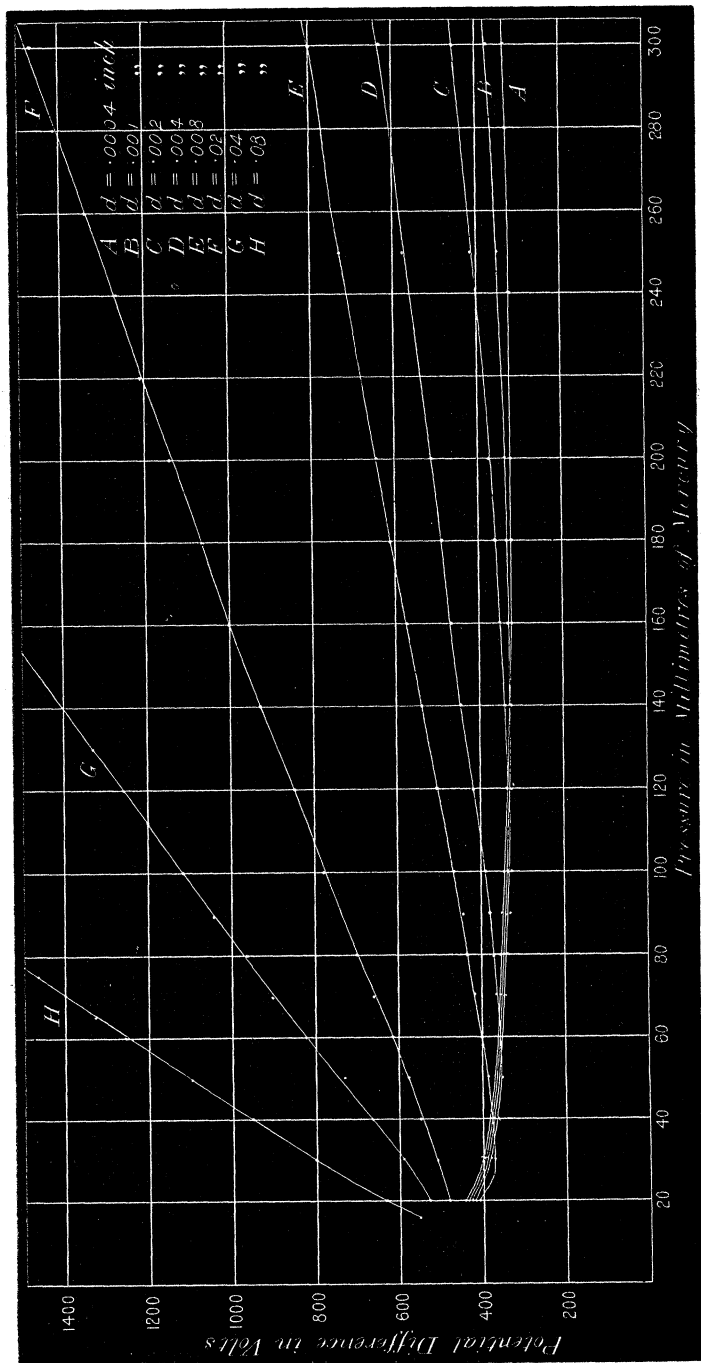
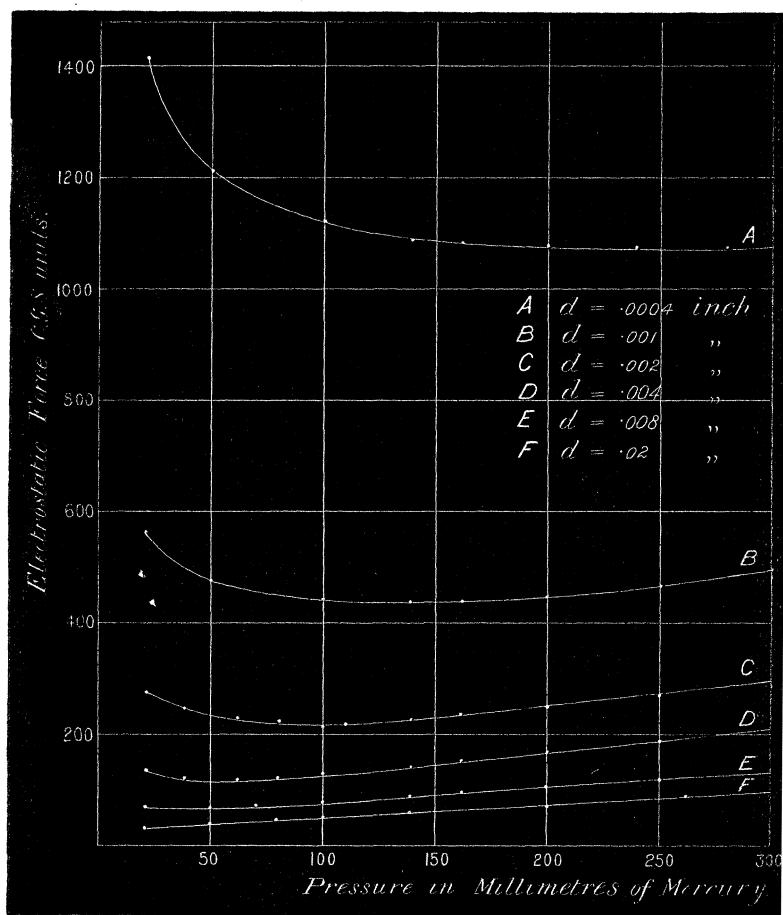


FIG. 3.

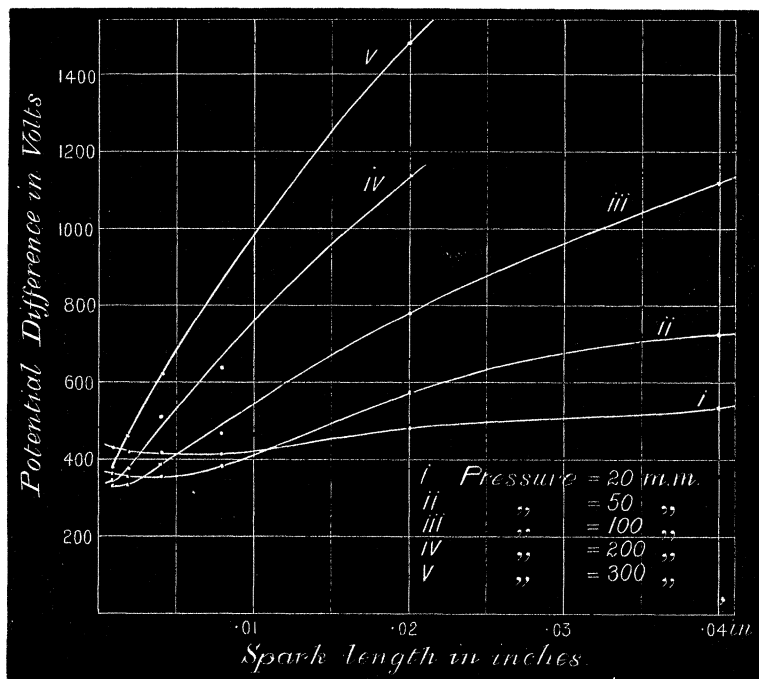


These results, and the curves representing them, present two features, already mentioned, which call for remark. In the first place, the potential difference curves in fig. 2 exhibit minima at pressures which are relatively high. The following table (p. 107) gives the minima shown by the curves, as drawn in fig. 2.

In every series of observations these minima were well marked, and for different series the pressures corresponding to the minimum potential difference for a given spark-length were always in close agreement. These minima are considered again below, in connexion with the results of Part II.

In the second place, the potential difference curves in fig. 2 meet

FIG. 4.



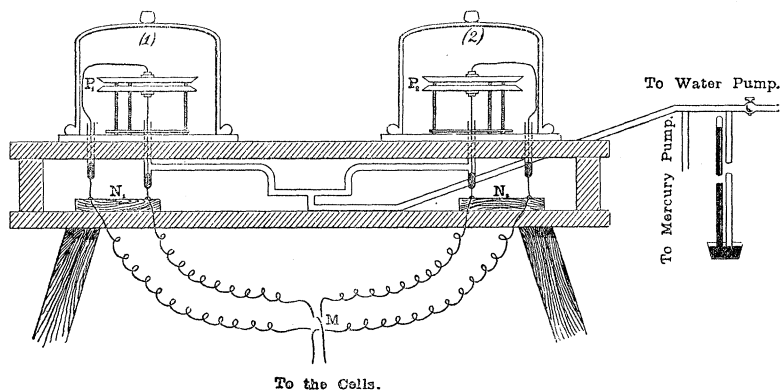
Spark-length, inches.	Minimum potential difference, volts.	Pressure, mm. of mercury.
0.0004	326	240
0.0010	330	150
0.0020	333	110
0.0040	354	55
0.0080	370	33

and pass above each other, or, which is the same thing, the curves in fig. 4, showing the relation between potential difference and spark-length for given pressures, also exhibit minima. This effect, though appearing consistently, was not very distinctly marked, but there were indications that it would be more apparent at lower pressures, and, therefore, it was thought advisable to submit it to more direct investigation. For this purpose new apparatus was fitted up, as described below.

PART II.

The apparatus used is sketched in fig. 5. Two pairs of plates at different distances apart, but with same air pressure, were arranged in parallel, so that an alternative path was offered to the discharge. The two pairs of plates were enclosed in two small receivers. The lower plate in each rested on an insulating stand; the upper plate was supported and separated from the lower by small thin discs of ebonite, mica, or glass. The four plates used were plane, and the thickness of the separating discs, as measured by the screw calipers, is taken as the length of the spark. The receivers rested on well-ground brass base plates, into each of which were sealed two narrow glass tubes, containing mercury, and having sealed platinum wires passing to the outside; flexible wires passed from the discharge-plates and dipped into the mercury in the tubes. One of these tubes served also, in each case, to give connexion with the pumps. Two pumps were used, the water pump for rapid exhaustion to about 30 or 40 mm. of mercury, the mercury pump for lower pressures. Pressures of from 2 to 3 mm. of mercury were easily reached, and could be maintained for any length of time.

FIG. 5.



The platinum wires, in connexion with the plates, dipped into mercury cups in the paraffin blocks N_1 and N_2 ; from these leads passed to the block M , where either one pair of plates, or both, could be connected to the leads passing to the cells. The cells were used in the same manner as before; the potential difference, however, instead of being reckoned as proportional to the number of cells applied, was measured directly by a cylinder quadrant electrometer. This was used in order to avoid a fresh examination into the uniformity of the cells.

The apparatus was set up, and the observations tabulated below were made in April, 1892. These observations were confined to pressures lower than 50 mm. In each case the two pairs of plates had air-gaps of very different length, so that each series of observations amounted to a determination of two separate potential difference and spark-length curves. The sparks were separately examined, until pressures were reached at which the potential differences necessary for discharge became nearly equal, and then the two pairs of plates were simultaneously connected to the cells. The crossing of the potential difference curves was thus directly verified, a slight lowering of the pressure transferring the discharge from the shorter to the longer air-gap.

The plates used in this experiment were, all four, plane and polished. Two were of brass, one of copper, and one of zinc. When the different plates were interchanged between the long spark-gap and the short, no difference was observed in the potential difference required for discharge at given difference and air-pressure. That there might be no doubt as to whether the discharge was passing actually between the plates, or was taking a longer path from edge to edge, the edges of the plates were only very slightly rounded off. At low pressures there was considerable tendency to a brush discharge from the edges, but this was considerably reduced by an extremely thin coating of shellac varnish.

The results given below are those of three single series of observations made on April 21, 22, and 23, respectively. All of these were repeated on the same or other days, and in all cases there was almost exact agreement. For convenience of reference these series are called A, B, and C, the suffix 1 referring to the left-hand, and the suffix 2 to the right-hand, spark-gap. As in the former case, the tables give corresponding pressure, potential difference in volts (V), and electrostatic force in C.G.S. units (F). Curves, similar to those given in fig. 2 and 3, representing potential difference and pressure, and electrostatic force and pressure, are also given in figs. 6 and 7.

A.

Pressure, mm. of mercury.	Curves A ₁ , fig. 6, and A ₁ , fig. 7. $d = 0.03$ in.		Curves A ₂ , fig. 6, and A ₂ , fig. 7. $d = 0.082$ in.	
	V ₁ , volts.	F ₁ , C.G.S. units.	V ₂ , volts.	F ₂ , C.G.S. units.
50.0	611	26.7	983	15.7
28.0	494	21.6	712	11.4
15.0	438	19.1	539	8.6
10.0	428	18.7	488	7.8
5.5	462	20.2	480	7.7
2.5	731	32.0	649	10.4

B.

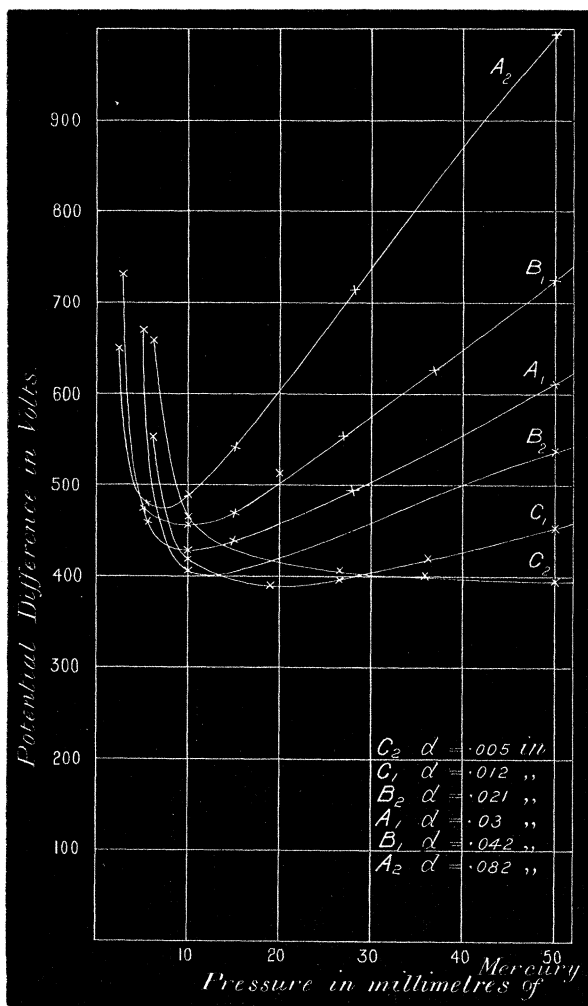
Pressure, mm. of mercury.	Curves B ₁ , fig. 6, and B ₁ , fig. 7. $d = 0.042$ in.		Curves B ₂ , fig. 6, and B ₂ , fig. 7. $d = 0.021$ in.	
	V ₁ , volts.	F ₁ , C.G.S. units.	V ₂ , volts.	F ₂ , C.G.S. units.
50	726	22.7	535	33.4
37	626	19.6	488	30.5
27	554	17.3	446	27.8
20	513	16.1	419	26.1
15	469	14.7	405	25.1
10	458	14.3	407	25.4
5	478	14.9	670	41.9

C.

Pressure, mm. of mercury.	Curves C ₁ , fig. 6, and C ₁ , fig. 7. $C_1 d = 0.012$ in.		Curves C ₂ , fig. 6, and C ₂ , fig. 7. $C_2 d = 0.005$ in.	
	V ₁ , volts.	F ₁ , C.G.S. units.	V ₂ , volts.	F ₂ , C.G.S. units.
50.0	454	49.6	397	104
36.0	422	46.2	402	105
26.0	397	43.5	408	107
19.5	389	42.6	414	109
10.0	420	46.0	467	122
6.0	552	60.6	660	173

It ought to be mentioned that the values here given for the spark-length d can only be regarded as approximations, as the pressure applied in measuring the thickness of the separating disks by the

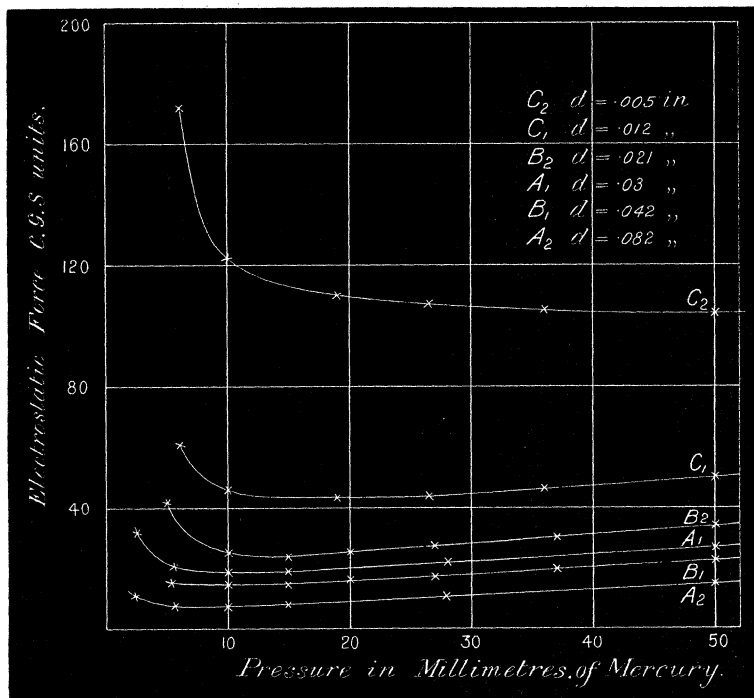
FIG. 6.



screw caliper might be very different from that due to the weight of the supported plate, especially in those cases in which several thicknesses of mica or ebonite were used. The essential point of this part of the investigation, however, was not the accurate determination of spark-length, but the direct comparison of discharge across two spark-gaps known to be of very different length.

The following table, similar to that given on p. 107, gives corresponding values for minimum potential difference, spark-length, and pressure, as deduced from the curves of fig. 6:—

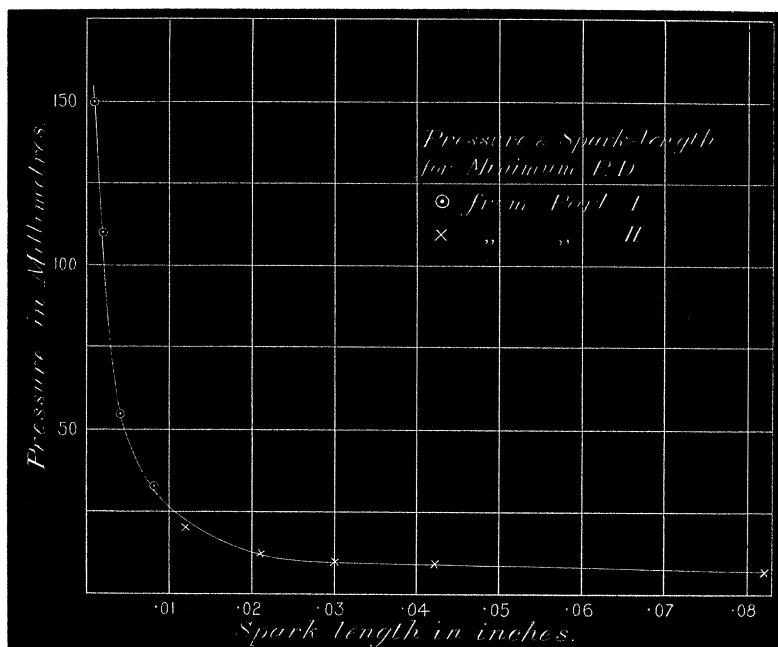
FIG. 7.



Spark-length, inches.	Minimum potential difference, volts.	Pressure, mm. of mercury.
0.012	390	19
0.021	400	12
0.030	428	10
0.042	458	9
0.082	475	7

The curve given in fig. 8 represents corresponding values of air pressure and spark-length for minimum potential difference. The points marked on this curve by a dot are taken from the results of Part I, those marked by a cross from the results of Part II. The long straight portions of the curve cannot be regarded as quite accurate, for the following reasons:—That portion which lies close to the vertical (pressure) axis refers to the extremely short spark-lengths of Part I, in measuring which an error in the screw-reading or in the zero adjustment might be a considerable fraction of the

FIG. 8.



whole distance, and that portion which lies close to the horizontal (or spark-length) axis refers to the low pressures of Part II, in measuring which a small error might again make considerable difference. These portions apart, it will be noticed that the more curved portion of the curve is a fairly close approximation to a rectangular hyperbola, as may be seen from the following table:—

Pressure, mm. of mercury.	Spark-length, thousandths of an inch.	Product.
60	3.8	228
50	4.8	240
40	6.4	256
30	8.8	264
20	12.8	256
10	26.5	265

The portions of the curve more distant from the origin show considerable divergence from the hyperbola, though perhaps, as has been pointed out, not more than might be due to errors of observation.

The appearance of the spark-discharge changed with the pressure in the usual manner. At ordinary pressures the discharge was a bright white spark, gradually passing, as the pressure was lowered, into a purplish glow. In the case of the flat and convex discs of Part I, the purple discharge, at first central and narrow, gradually spread out and at low pressures filled the space between the plates. The appearance of the spark could not, however, be carefully examined, as the circuit was always broken as soon as discharge occurred in order to avoid damage to the surfaces of the plates. When these were examined by breathing on them after a number of sparks had passed at low pressures, it was always found that the part of the surfaces most affected by the discharge was an annulus at some little distance from the centre. With the flat plates used in Part II, the discharge was generally diffused over the space between the plates.

Observations of spark discharge between plates in air at different pressures have been made by Warren de la Rue and H. Müller* and by Macfarlane.† Their results do not present the features to which attention has been called in the present paper, nor could they do so, as the curves for potential difference and pressure for the spark-lengths they examined would show no evidence of a minimum potential difference at the lowest pressures they considered. In both cases the spark-length was about 0.13 inch, and the lowest pressure 20 mm. of mercury.

In conclusion, I have to express my thanks to Professor J. J. Thomson, to whom I have been indebted for advice and suggestions at every point of this investigation.

VII. "Electro-chemical Effects on Magnetising Iron. Part IV."

By THOMAS ANDREWS, F.R.S., M.Inst.C.E. Received May 16, 1892.

Influence of Magnetisation on Corrosion of Steel.

In connexion with, and during the progress of, the electrical portion of my research on "Electro-chemical Effects on Magnetising Iron," Parts I, II, and III ('Roy. Soc. Proc.,' vols. 42, 44, and 46), numerous gravimetric experiments were conducted, with the object of investigating the influence of magnetisation on the corrosion of iron and steel. I selected as the corrosive fluid a solution of cupric chloride, being partly guided in this choice by the results obtained with solutions of this salt in the electrical portion of the investigation.

* 'Phil. Trans.,' vol. 171, pp. 75—82, 1880.

† 'Trans. Roy. Soc. Edinb.,' vol. 28, p. 642, 1878.

FIG. 1.

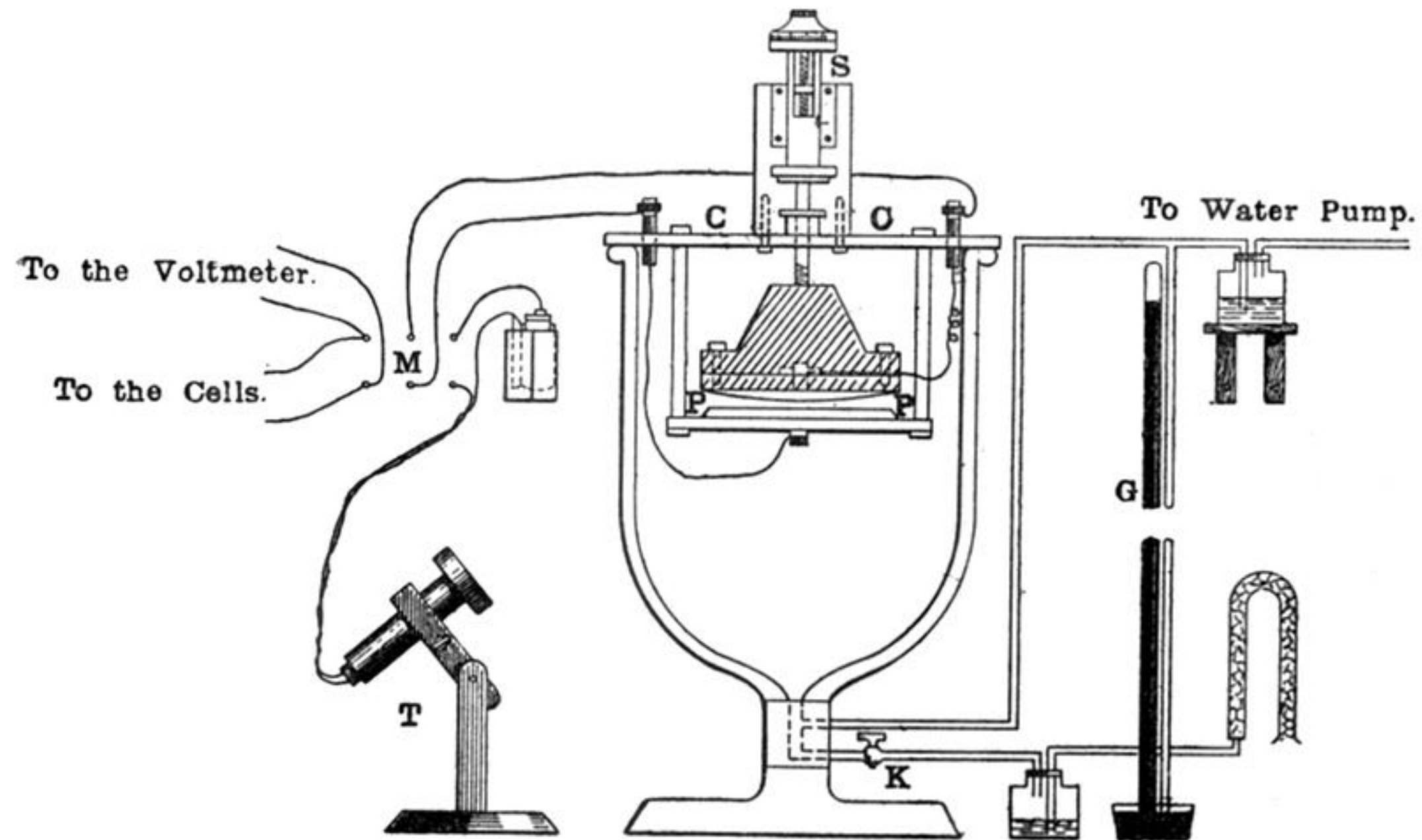


FIG. 2.

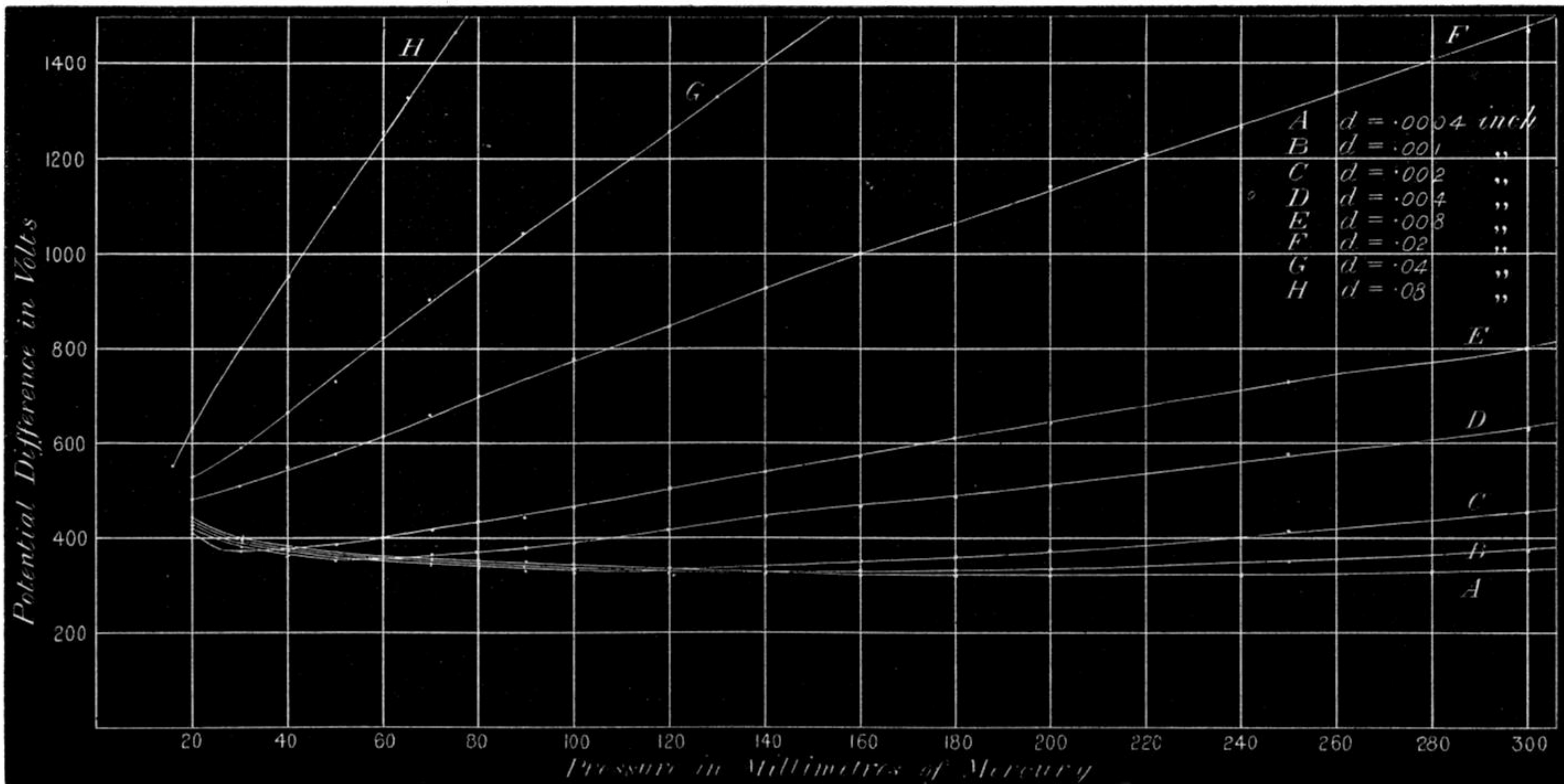


FIG. 3.

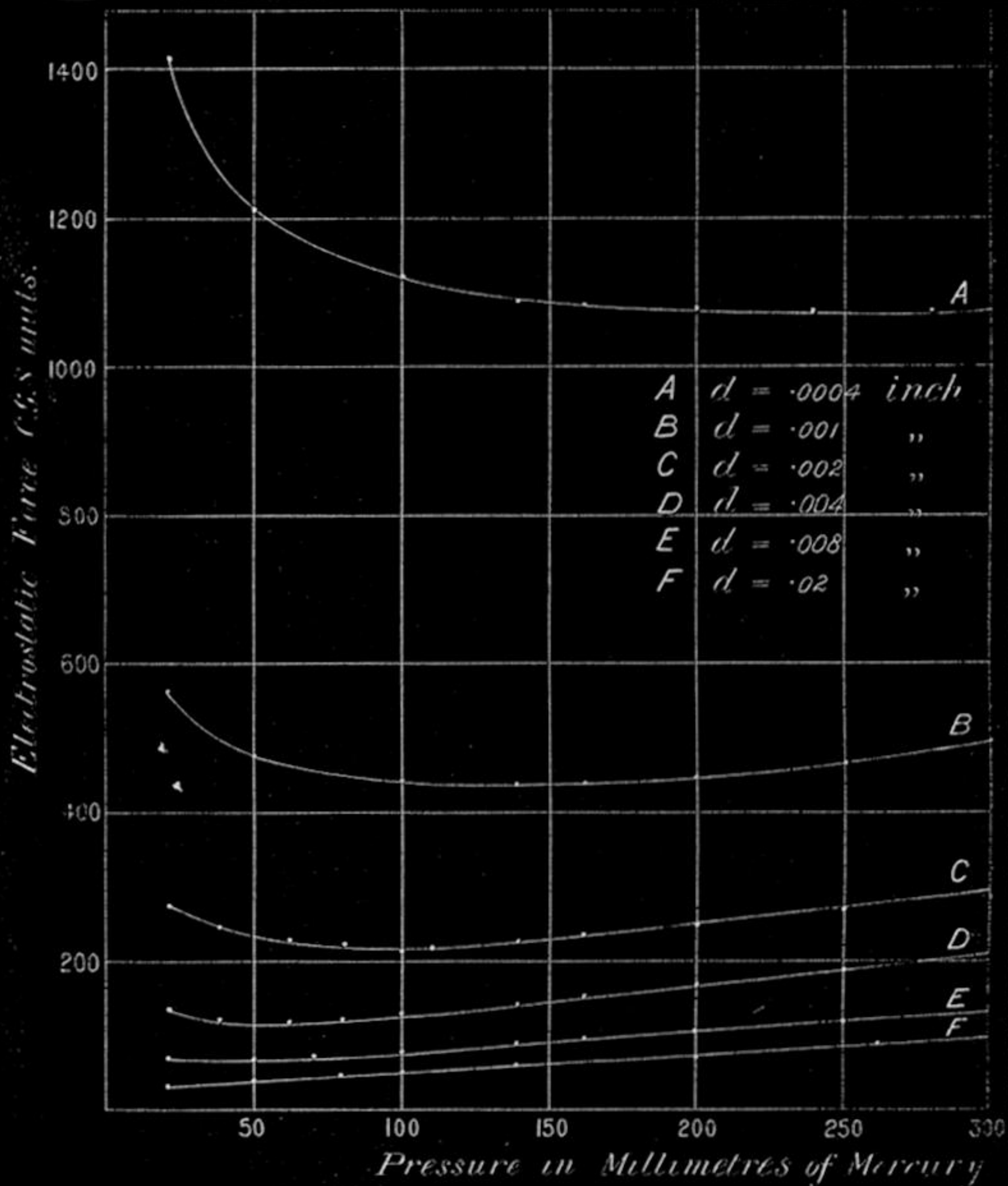


FIG. 4.

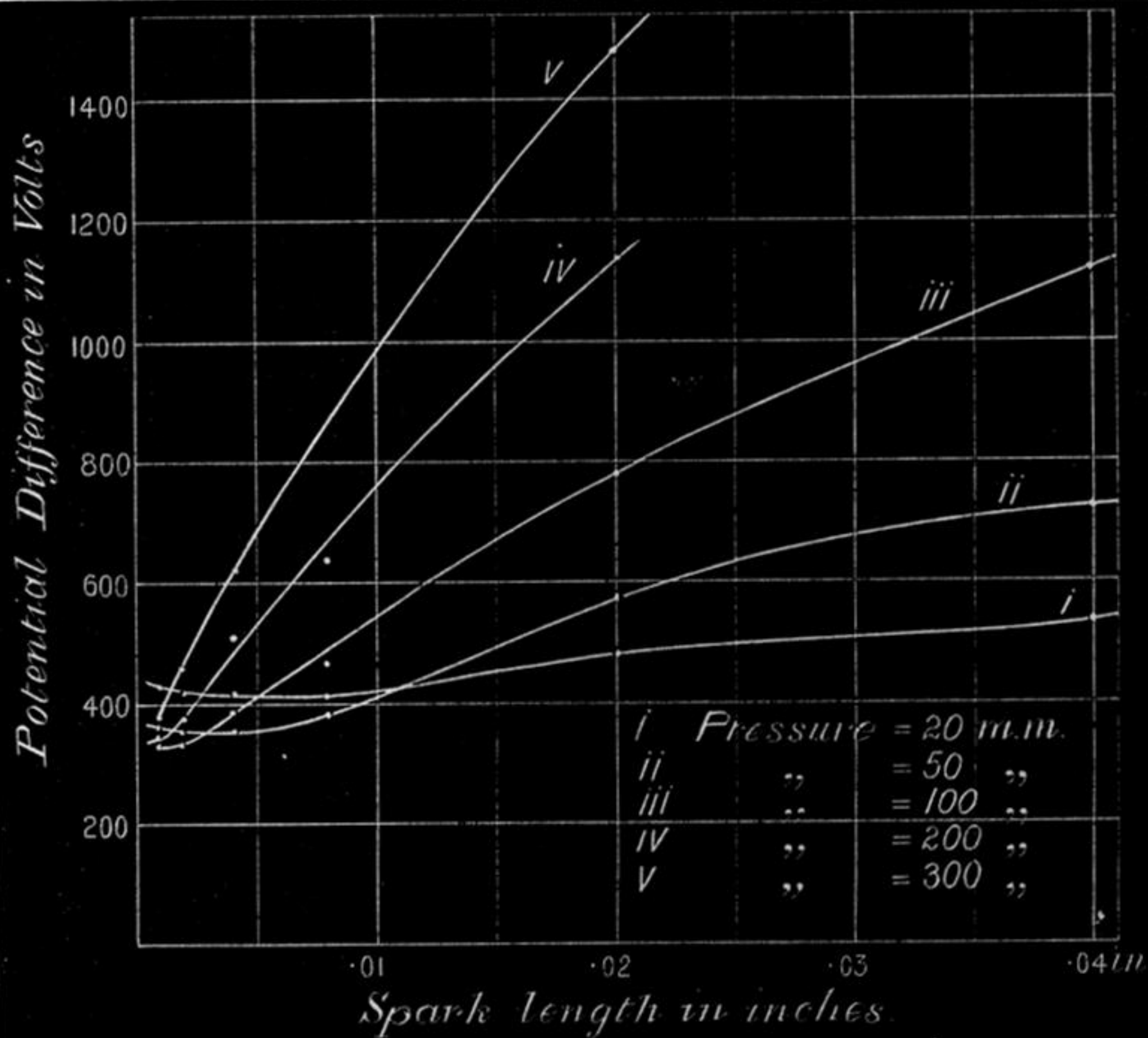


FIG. 5.

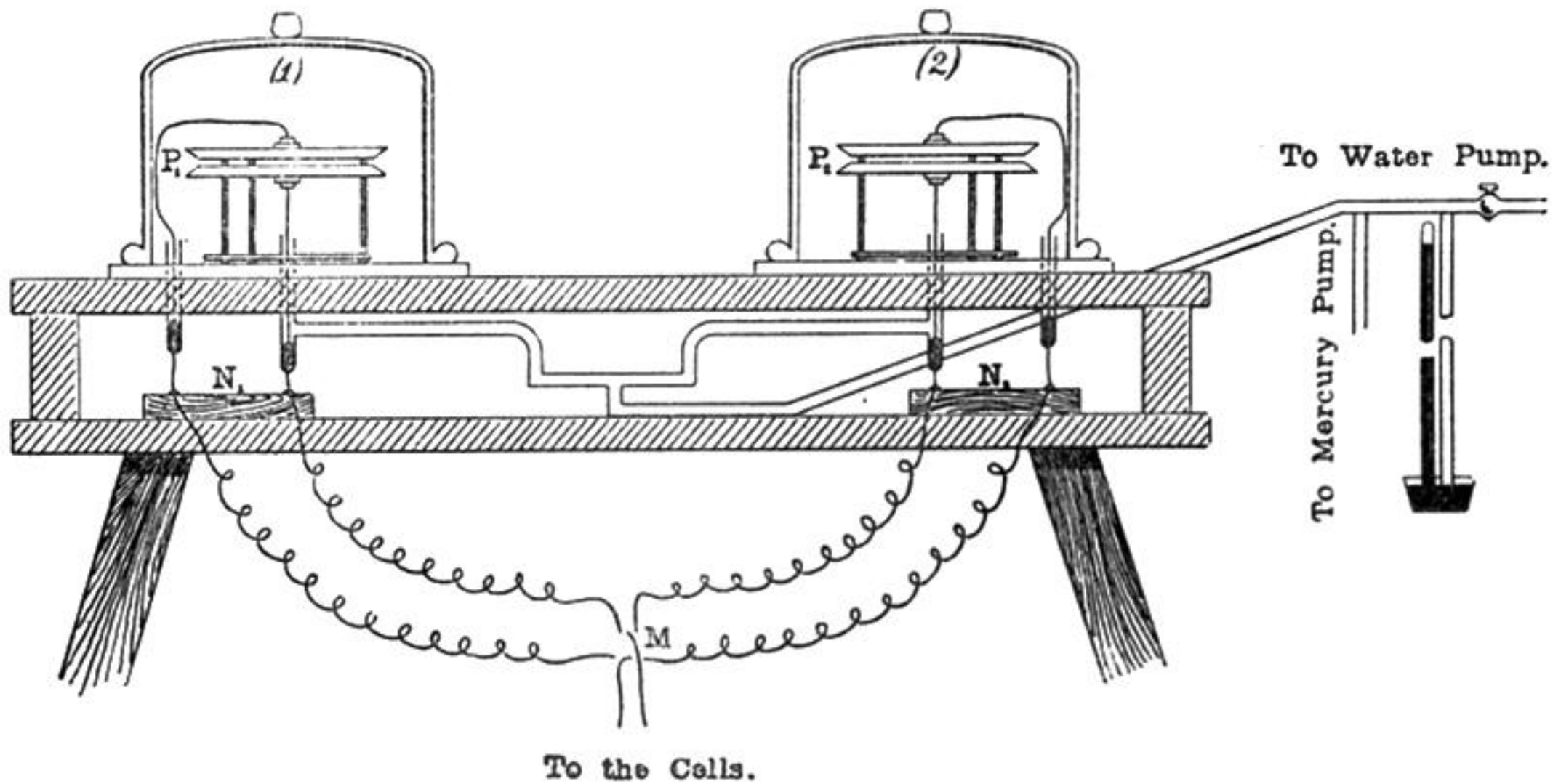


FIG. 6.

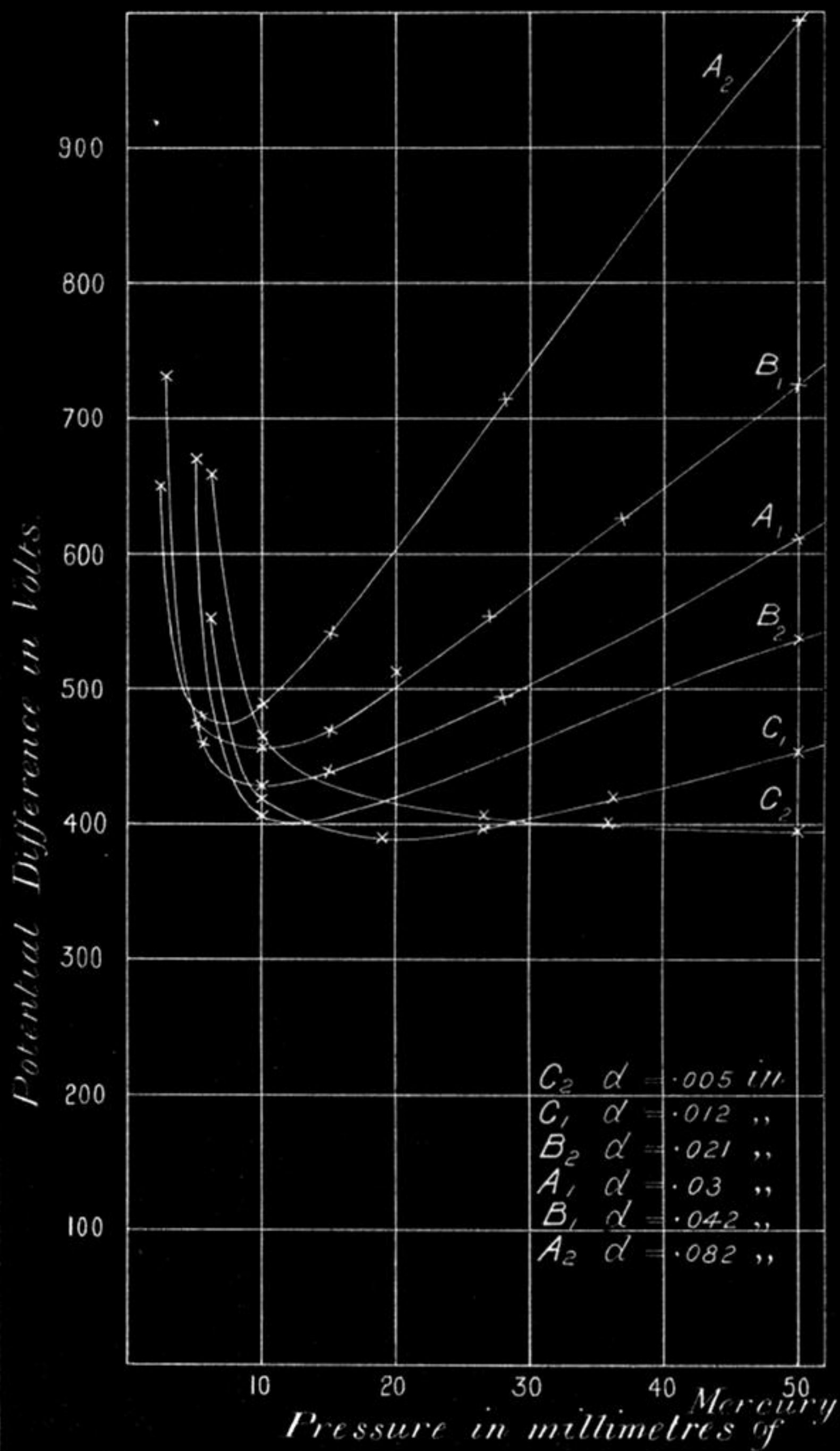


FIG. 7.

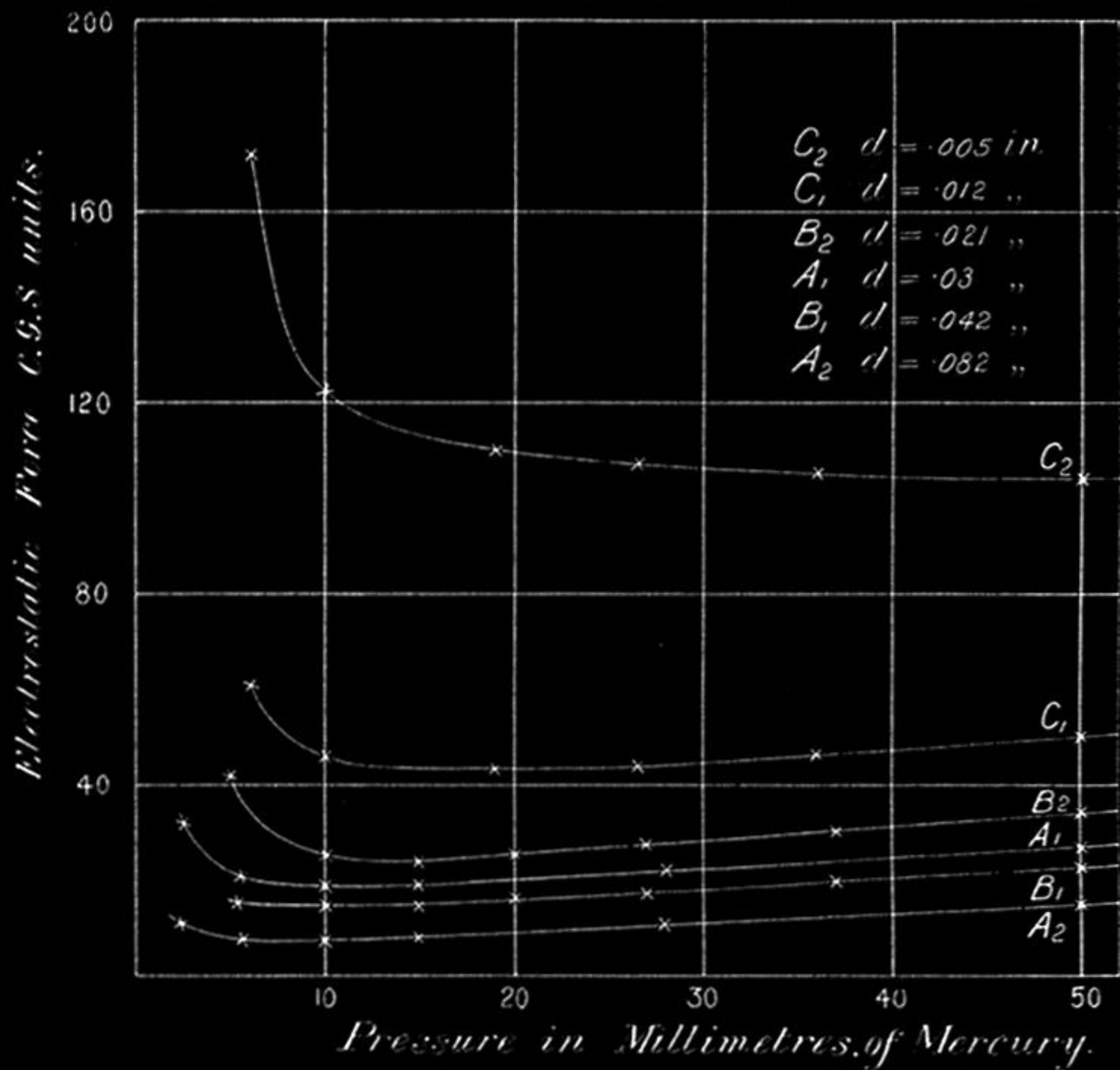


FIG. 8.

